IDA

INSTITUTE FOR DEFENSE ANALYSES

Subtier Assessment: Advanced Suspension Systems for Tracked Combat Vehicles

J. E. Hartka, Project Leader

August 1998

IDA Paper P-3448
Log : H 98-002128

This work was conducted under contract DASW01 94 C 0054, Task T-AV5-1561, for the Director of Industrial Capabilities and Assessments in the Office of the Deputy Under Secretary for Industrial Affairs and Installations. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

INSTITUTE FOR DEFENSE ANALYSES

IDA Paper P-3448

Subtier Assessment: Advanced Suspension Systems for Tracked Combat Vehicles

J. E. Hartka, Project Leader

PREFACE

The Institute for Defense Analyses (IDA) has established an Industrial Analyses Center (IAC) to provide the Office of the Secretary of Defense (OSD) with objective and independent analyses that characterize and assess industrial capabilities for acquisition and support of weapon systems. The IAC performs a range of analyses that address industrial issues associated with changing industry structure, competition, and industrial and technology capabilities at the prime and subtier contractor levels.

Firms reviewed in this study supply much of the information that IDA uses to perform its analyses. IDA may not be able to independently validate material supplied. As a result, future adjustments to these studies may be required to correct information provided by industry sources. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor do its contents necessarily reflect the official position of that Agency.

This document reports on an analysis done by IDA to address industrial issues associated with subtier suppliers for tracked combat vehicles, i.e., those suppliers of components and subsystems rather than prime contractors.

Clearly, the significance of any analysis is critically dependent on the quality and completeness of the data available to the analysts. The many people who provided information are cited in an appendix and the study team thanks them heartily for their cooperation. Similar thanks go to the members of IDA's professional staff who were not formal members of the study team but who were of great help in identifying and querying various data bases. This study derived immense benefit from the thoughtful guidance offered by the sponsor and by the internal IDA reviewers, and the study team is grateful for their patient assistance. Finally, because much of a study's utility depends how well it is presented, special thanks are also due to the project secretary, Mrs. Patricia Hatter, and the project editor, Mrs. Paula Greer.

(This page is intentionally blank.)

CONTENTS

Appendixes

(This page is intentionally blank.)

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Tracked combat vehicles (TCVs) are key elements of a modern ground force. Speed and mobility are two of the determinants of TCVs' survivability and effectiveness. TCV speed and mobility are, however, limited by the bouncing and rolling imposed on the crews as the TCVs maneuver over rough terrain. Suspension systems are designed to mitigate these forces so that a TCV can travel at greater speeds over rougher terrain without exceeding the crew's tolerance.

As a result of various mergers and acquisitions, there are two prime contractors for TCVs. It is important for OSD to know whether this contraction in the number of TCV suppliers has resulted in a weak industrial base for the production of major components of TCVs. This report documents the results of an investigation of the issue as it relates to advanced suspension systems.

Suspension systems embody two basic functions. The first is an energy storage mechanism. Generally this is some type of spring. The second is an energy dissipation mechanism. This is analogous to a shock absorber in a car. Research and development (R&D) has demonstrated that suspensions can be significantly improved by introducing some degree of control over the rate at which energy is stored and dissipated. In this document, suspensions with this control are called adaptive suspensions. If an additional a mechanism is provided to introduce energy and not just store and dissipate it, then the system is called an active suspension.

The study team investigated the requirements for advanced suspension systems as well as the capability to design, manufacture, and integrate them into TCVs. We discussed the issue with people in the government, TCV contractors, R&D centers, and companies that produce heavy construction equipment for mining and construction. We also used specialized databases and open literature, including searches via the World Wide Web. The resulting data base includes information about suppliers of components for standard (i.e., passive) suspensions, as well as the adaptive and active systems mentioned above. The following points highlight the findings:

- There are no current production requirements for adaptive and active suspensions on TCVs.
- R&D on advanced suspensions is widespread.
- The government is funding some of the R&D, but the full amount is unknown because some of the work is being

done in the context of larger programs that encompass more than just suspensions.

- The three U.S. companies that currently produce standard suspensions (i.e., suspensions without adjustable control of either energy storage or dissipation) for TCVs appear to be fully capable of manufacturing adaptive and active suspensions. They are United Defense Limited Partnership; General Dynamics Land Systems; and Cadillac Gage-Combat Vehicles, an operating group of Textron Marine and Land Systems.
- Two of those companies—General Dynamics Land Systems and Cadillac Gage—and numerous R&D centers are designing newer suspensions including adaptive and active systems.
- Several foreign companies manufacture suspension systems and related components for TCVs.
- There are many U.S. and foreign manufacturers of suspension systems for heavy construction and mining vehicles.
- The production of suspension systems, even for very heavy vehicles, does not apparently require unique or hard-to-find manufacturing capabilities. Torsion bars for standard suspensions in the heaviest TCVs are a possible exception, but the requirement for them is very low.

In short, the industrial capability to produce advanced suspensions, should they be required in the future, does not appear to warrant urgent concern.

SUBTIER ASSESSMENT:
ADVANCED SUSPENSION SYSTEMS FOR TRACKED COMBAT VEHICLES

This briefing book documents one of a series of assessments concerning the industrial base underlying the production of systems of interest to the Department of Defense. This particular assessment addresses advanced suspension systems for tracked combat vehicles (TCVs). These are considered subtier systems. The specific objective of the task order for subtier assessments is quoted below.

> *To establish a comprehensive understanding of a key product or technology area of concern and identify potential avenues for mitigating situations that would affect competition or innovation with specific emphasis on vertical integration effects. Additionally to provide a preliminary set of baseline data to increase the sponsor's ability to respond to fast reaction issues in the specified area and to enable decisions on directions for further study. Special focus will be given to supplier viability and capability; market demands (current and projected); and the evenness of competition.*

OUTLINE

INTRODUCTION

DESCRIPTION OF RESEARCH AND INTERMEDIATE PRODUCTS

FINDINGS AND CONCLUSIONS

(This page is intentionally blank.)

INTRODUCTION

In general, the power that humans and mechanical structures can tolerate typically limits the maximum speed that combat vehicles can sustain, particularly when operating off-road. Research has shown that for human beings, this limit is approximately 6 watts. That is, an average soldier or marine cannot absorb more than 6 watts without suffering fatigue, which limits his ability to continue the mission. This power is transmitted to occupants by the bouncing, swaying, and other motion that the vehicle imparts to them. Thus, the average power transmitted to a vehicle's occupants is one characteristic that designers attempt to mitigate by means of the vehicle's suspension system.

The power mentioned above depends strongly on the speed of the vehicle and the roughness of the terrain over which it travels. Another feature that is affected by a vehicle's suspension system, but which is less sensitive to speed, is the vehicle's ability to traverse obstacles such as ditches or boulders. This is critical to both a vehicle's mobility and to its ability to provide an appropriate base for any weapons that constitute its armament.

Traditional suspension system designs (i.e., those that have been used in the past on U.S. TCVs) appear to have reached the limit of their potential. The components of various types of suspension systems will be discussed in more detail later. The message here is that TCVs cannot be made to go much faster in operational environments unless their suspension systems are changed substantially to manage how they absorb and give back energy as the vehicle traverses rough terrain.

Tracked vehicles for commercial use, e.g., bulldozers, are not generally required to operate at the higher speeds (60 kph or more) expected of combat vehicles such as tanks. Therefore, the design and manufacture of advanced suspension systems for TCVs appears to be the exclusive domain of defense contractors.

INTRODUCTION

- THE MAXIMUM SPEED THAT A COMBAT VEHICLE CAN SUSTAIN IS LIMITED BY THE POWER THE STRUCTURE AND THE OCCUPANTS ABSORB
  - — Humans cannot generally sustain a power absorption of more than 6 watts for typical periods of combat duty
- OTHER PERFORMANCE FACTORS SUCH AS THE KIND OF TERRAIN THAT CAN BE TRAVERSED AND THE ABILITY TO FIRE WEAPONS WHILE ON THE MOVE DEPEND ON THE ABILITY TO MAINTAIN A STABLE BASE
- TRADITIONAL SUSPENSION SYSTEM DESIGNS APPEAR TO HAVE ACHIEVED THEIR MAXIMUM POTENTIAL
- THERE APPEARS TO BE LITTLE COMMERCIAL DEMAND FOR ADVANCED SUSPENSION SYSTEMS FOR TRACKED VEHICLES

Appendix A contains information about current tracked combat vehicle programs. (It also identifies possible future combat vehicle programs that may warrant study as they mature.) It too shows that there are two TCV prime contractors: only United Defense Limited Partnership (UDLP) and General Dynamics Land Systems (GDLS) integrate components to build a complete combat vehicle. The seeming exception is Lockheed Martin Vought, which is the prime contractor for the Multiple Launch Rocket System (MLRS). However, even in this case the vehicle is produced by UDLP and the prime contractor integrates the weapon system into the vehicle.

Discussions with people at these two organizations reveal that both of these contractors, either directly or via other contractors that they have since absorbed, have been both suppliers and purchasers of complete suspension systems for installation in TCVs. (See Appendix B for a list of organizations and points of contact.)

The market for such vehicles currently is supporting only two U.S. contractors and the suppliers of applicable suspension systems appear to be similarly limited. (See Appendix C.) It is therefore reasonable and prudent for OSD to assess the availability and viability of sources for advanced suspension systems for future tracked combat vehicles.

INTRODUCTION (Cont'd)

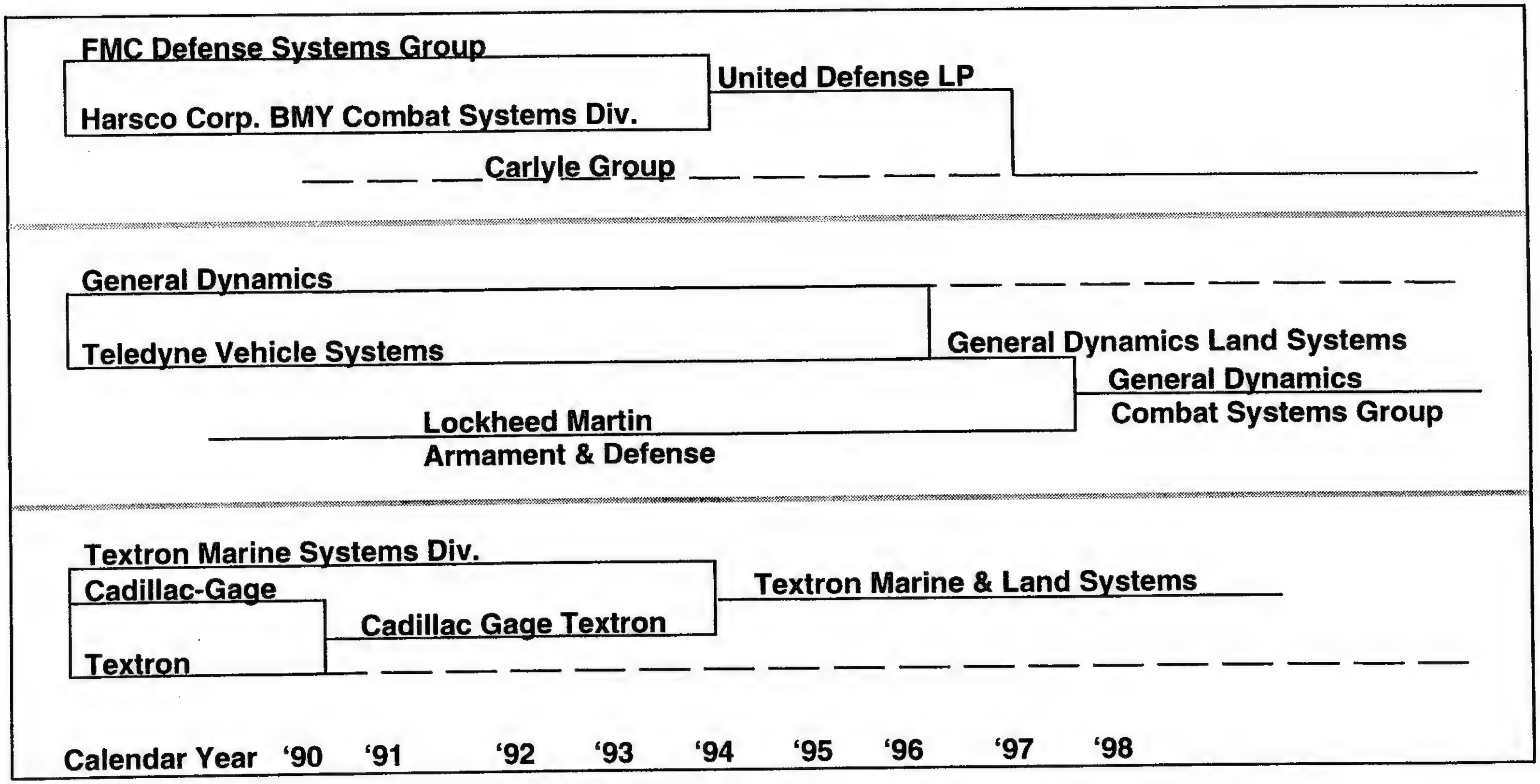
- THERE ARE TWO PRIMARY TRACKED COMBAT VEHICLE (TCV) INTEGRATORS: UNITED DEFENSE LIMITED PARTNERSHIP (UDLP), AND GENERAL DYNAMICS LAND SYSTEMS (GDLS)
  - Lockheed Martin Vought Systems is the integrator for the MLRS launcher but the chassis is built by UDLP

- UDLP, GDLS, AND THEIR PREDECESSORS HAVE BEEN BOTH SUPPLIERS AND PURCHASERS OF SUSPENSION SYSTEMS

- THE OBJECTIVE OF THIS SUBTIER ASSESSMENT IS TO ASSESS THE AVAILABILITY AND VIABILITY OF SOURCES FOR ADVANCED SUSPENSION SYSTEMS FOR FUTURE TRACKED COMBAT VEHICLES

This slide illustrates the consolidation which led to the current two integrating manufacturers of TCVs. As will be discussed later, the study also identified Cadillac-Gage Textron as a suspension system supplier. This figure therefore also shows where Cadillac-Gage Textron stands in the Textron corporate structure.

CONSOLIDATION OF TCV AND TCV SUSPENSION SYSTEM PRODUCERS



United Defense Limited Partnership, General Dynamics land systems, and Cadillac-Gage Textron continue as named entities within their larger corporate structures.

Dashed lines (— — —) indicate the continuation of the highest corporate level.

(This page is intentionally blank.)

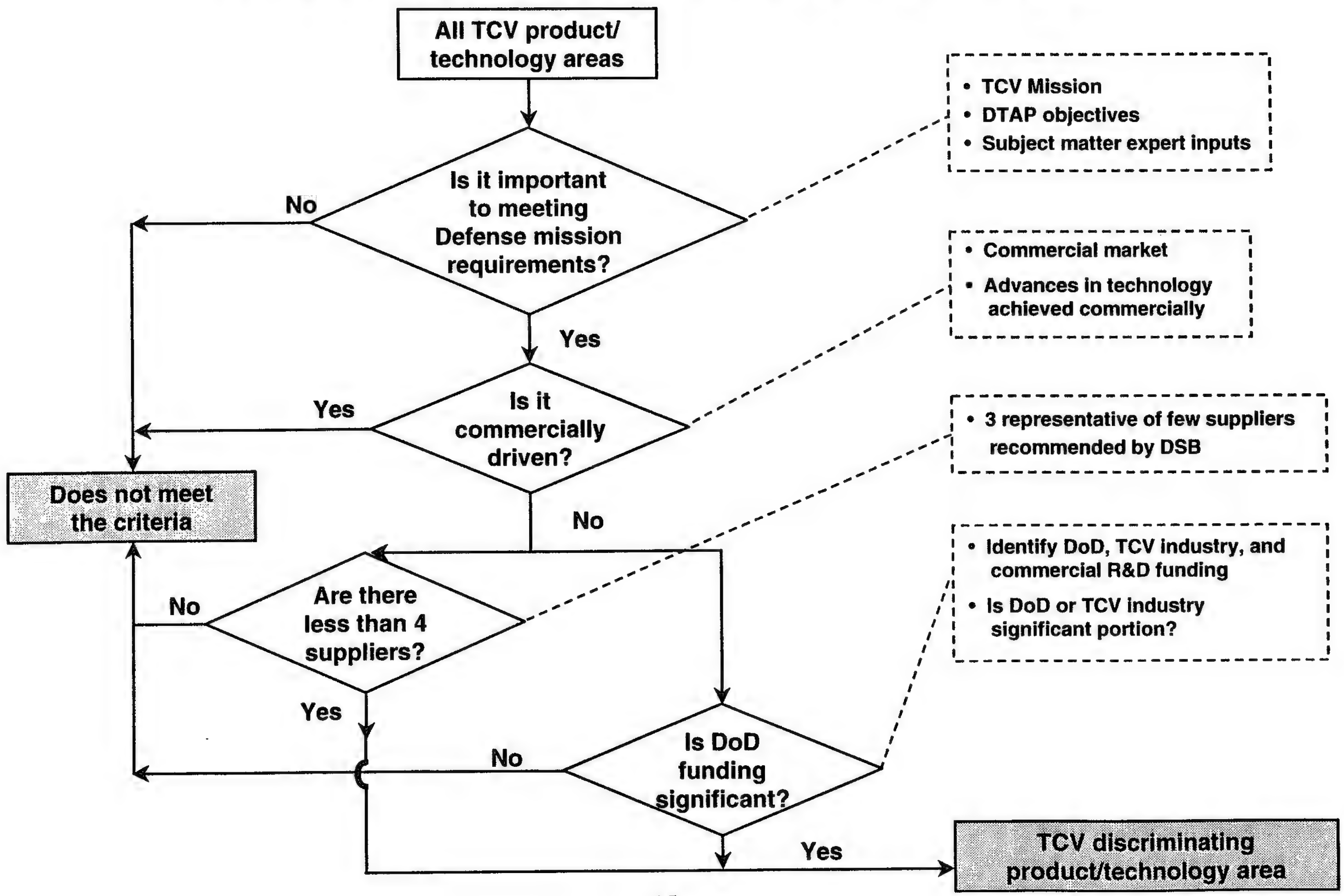
DESCRIPTION OF THE RESEARCH AND PRODUCTS

This figure is adapted from a more general figure that was produced by the sponsor's staff. It illustrates the decision logic that allows one to conclude whether the industrial base for the production of advanced suspensions for TCVs should be a concern to the sponsor or not.

Entries in boxes defined by dashed lines expand on the related questions and indicate the source of data or the approach to answering them.

In brief, the capability to produce advanced suspensions is a concern if they are important to defense, the capability is not driven by commercial demands, and there are either fewer than four suppliers or DoD funding is significant to maintaining the capability.

DECISION LOGIC FOR TCV KEY PRODUCT AND TECHNOLOGY AREAS



Clearly TCVs, their subsystems and components are produced by industries in many nations. The facing matrix indicates the priority the study team associated with the various combinations of U.S. and Foreign TCV integrators and suspension system suppliers (e.g. U.S.—U.S. has the highest priority).

STUDY PRIORITY MATRIX

Combat Vehicle Systems	Suspension System Suppliers: US	Suspension System Suppliers: Foreign
US	1	3
Foreign	2	4

The original definition of this subtier task encompassed only "active suspension systems." The study team's initial research suggested that this focus was perhaps too narrow. The characteristics that distinguish one type of suspension from another are discussed later. The important ideas at this point are that advanced, but still not adaptive or active, suspension systems are being developed and seem to represent the current state of the art for TCV applications. Also, there is a great deal of similarity among suspension systems applicable to wheeled and tracked combat vehicles and adaptive and active suspensions are being investigated for use in U.S. combat vehicles of both types.

Based on these observations the study team concluded that the research should be expanded to address advanced suspensions that are applicable to combat vehicles. The only limitation is that the suspension must have progressed beyond engineering analyses to some level of demonstration. Information concerning suppliers for passive suspensions has also been compiled because of the industrial capacity and experience base those suppliers represent.

SCOPE

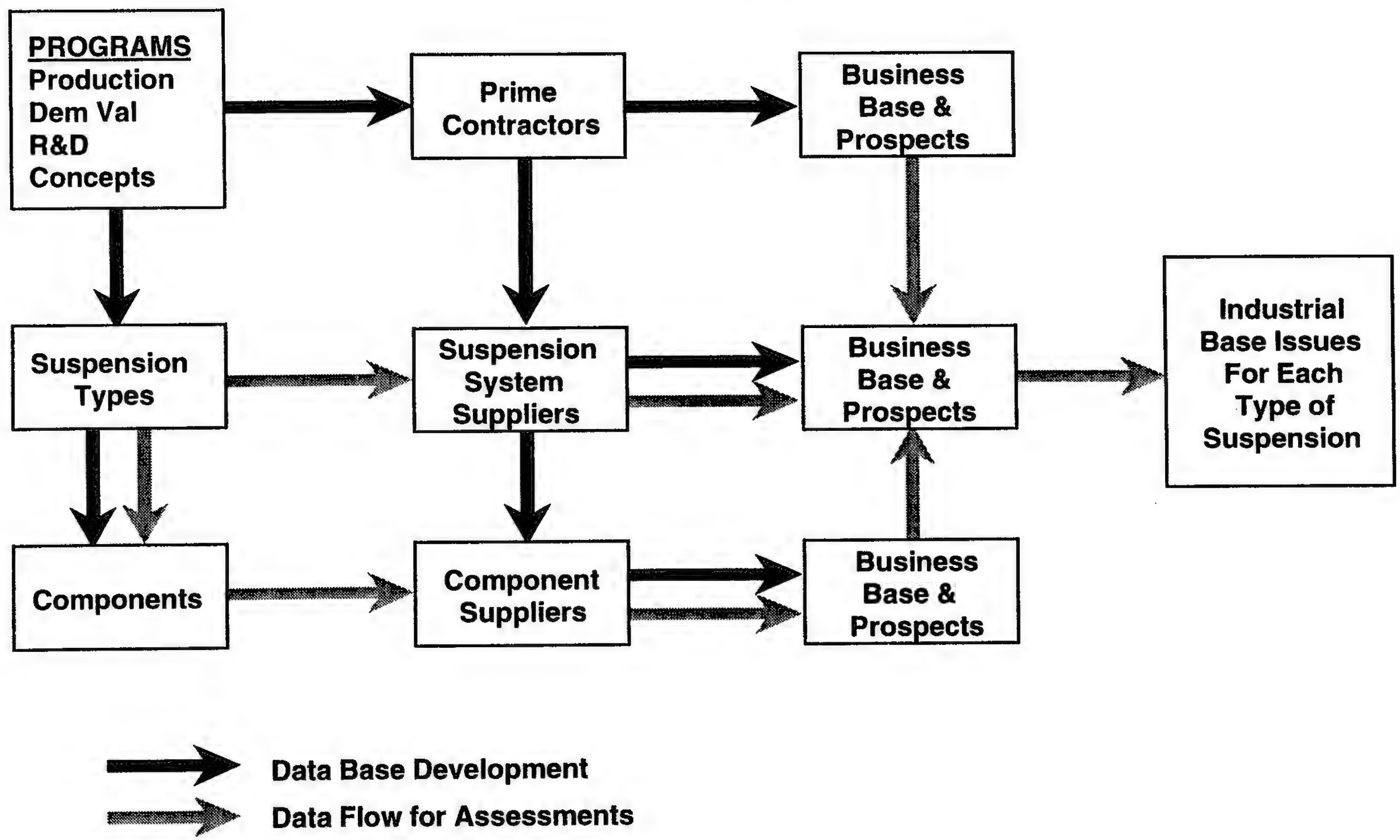
- ORIGINALLY SPECIFIED TOPIC WAS ACTIVE SUSPENSION SYSTEMS FOR TRACKED COMBAT VEHICLES

- INITIAL RESEARCH SUGGESTED VALUE IN LOOKING BEYOND THIS TOPIC
  - Include adaptive (semi-active) suspensions because they apparently represent the state of the art for systems in production and development
    - Active suspensions are in development for commercial vehicles and in the research or concept exploration phase for U.S. combat vehicles
  - Include wheeled vehicles because of similarity of the design and manufacture of some components

- WE DEFINE ADVANCED SUSPENSION TO MEAN AN ADAPTIVE OR AN ACTIVE SUSPENSION AS WELL AS MODERN PASSIVE SUSPENSION SYSTEM FOR TCVs

The task order calls for two types of product—an assessment of industrial capabilities and a data base that the sponsor can use in the future to respond to related questions. This figure illustrates the study team's approach to compiling and using the data.

DATA FLOWS


PROGRAMS
Production
Dem Val
R&D
Concepts
Prime Contractors
Business Base & Prospects
Suspension Types
Suspension System Suppliers
Business Base & Prospects
Industrial Base Issues For Each Type of Suspension
Components
Component Suppliers
Business Base & Prospects
Data Base Development
Data Flow for Assessments

The data base was gathered from many sources. Discussions with people in government, industry, and R&D laboratories provided most of the insights into the state of the art, the direction of current activities, and anticipated problems. Appendix B lists the primary contacts.

Specialized data bases were also checked. Where necessary, subscriptions and CD ROMs were provided by the IDA Center for Industrial Assessment. These were particularly useful for investigating the history of the various companies that are involved in TCVs in general and in suspension systems for them in particular.

In addition, the study team also searched the Worldwide Web with most of the commonly available search engines. This provided far too many leads to be searched exhaustively, but at the same time it identified related work at universities, engineering colleges, and R&D centers that is proceeding without DoD sponsorship.

A particularly notable source of information concerning suppliers of standard suspension system components was a draft study (to be published in the first quarter of 1999) done by the Production Base Management Team at the U.S. Army Tank and Automotive Command (TACOM).

DATA SOURCES

- INTERVIEWS WITH PEOPLE IN GOVERNMENT, MANUFACTURING, AND R&D LABORATORIES
  - — Primary contacts listed in Appendix B
- SPECIALIZED DATA BASES MADE AVAILABLE VIA <u>IDA CENTER FOR INDUSTRIAL ASSESSMENT</u>
  - — Includes web sites and files distributed on removable disk
- OTHER GOVERNMENT AND CIVILIAN SECTOR WEB SITES

A suspension system connects the hull of a vehicle to its primary or "road" wheels. This is true even for TCVs because the tracks run around a set of wheels. The suspension system itself comprises some sort of elastic mechanism (e.g., a spring) that keeps the wheels and the hull separated while also allowing them to move relative to each other. A second component between the hull and the wheels is some sort of energy dissipation device. This is analogous to shock absorbers in trucks and cars. It keeps the wheel from continuing to bounce after the vehicle goes over a bump. These two mechanical functions must be performed even if in some applications they are both built into a single assembly.

There is a large variety of highly sophisticated suspension system designs, but they can be grouped into three broad types. This slide identifies the key distinguishing characteristics of the various types.

For ease of reference, we call the most common type of suspension "standard." The elastic support is a spring or its functional equivalent; that is, the spring can be a hydro-pneumatic device (a tube containing a piston and a gas or gas-liquid combination). Although the dissipator could be any sort of friction device, it is typically a hydro-pneumatic device built so that a piston forces the working fluid to flow from one chamber to another through one or more holes. Both the elastic support and the dissipator can be extremely sophisticated in their design. The feature that characterizes them as standard is that their operating characteristics are not changed without human intervention.

The next type of suspension is frequently called semi-active. However, different people interpret that term differently. We have chosen to sidestep the highly technical distinctions (and sources of argument) and use the term adaptive. In an adaptive suspension, one or more sensors and controllers determine how the hull is moving with respect to its road wheels and then continually and automatically adjust either the elastic support, the dissipator, or both. The same change need not and in fact should not be made at all of the wheels. For example, the suspension could be stiffened on only one side when the vehicle goes around a turn. Nevertheless, in an adaptive system, as in the standard system, the position of each wheel with respect to the hull is driven by the terrain and the inertia of the hull. When the vehicle goes over a bump the bump forces the road wheel up. When it goes over a hole, the road wheel is forced down by gravity and the stored energy in the spring.

Like adaptive suspensions, active suspension systems use sensors and control mechanisms to adjust the elastic support and the energy dissipation. In addition, however, active suspensions can add energy. That is, they can lift a road wheel away from a bump or force it down quickly into a hole to reduce the influence of the obstacle on the hull.

Regardless of type, the objective of the suspension system is to improve the ride and mobility of the vehicle. Ideally it should move as if it were on smooth tracks with little sway or side to side rolling as it turns.

MAJOR TYPES OF SUSPENSION SYSTEMS

- STANDARD (PASSIVE)
  - — Non-adaptive rates of storing and dissipating energy, i.e., they are not adjusted in real time based on the relative motion of the wheels and the hull
- ADAPTIVE (SEMI-ACTIVE)
  - — Adaptive rates of storing and dissipating energy
  - — Requires a controller and logic, but little external power
- ACTIVE
  - — Can adaptively introduce energy as well as change the rates of storing or dissipating energy
  - — Requires a controller, logic, and more external power than adaptive systems

In all cases, the objective of the suspension system is to improve the ride (including stability) and mobility of the vehicle.

- — *Ride is characterized by the power the occupants must absorb, must be ≤ 6 watts, and is directly related to speed*
- — *Mobility characterized by the percentage of terrain the vehicle can traverse*

This figure illustrates the principal components of a standard suspension system. The hatched regions designate where the suspension is attached to the hull. Although only two road wheels are shown, there could clearly be more on each side of a vehicle. For example, an M1 tank has seven road wheels on each side.

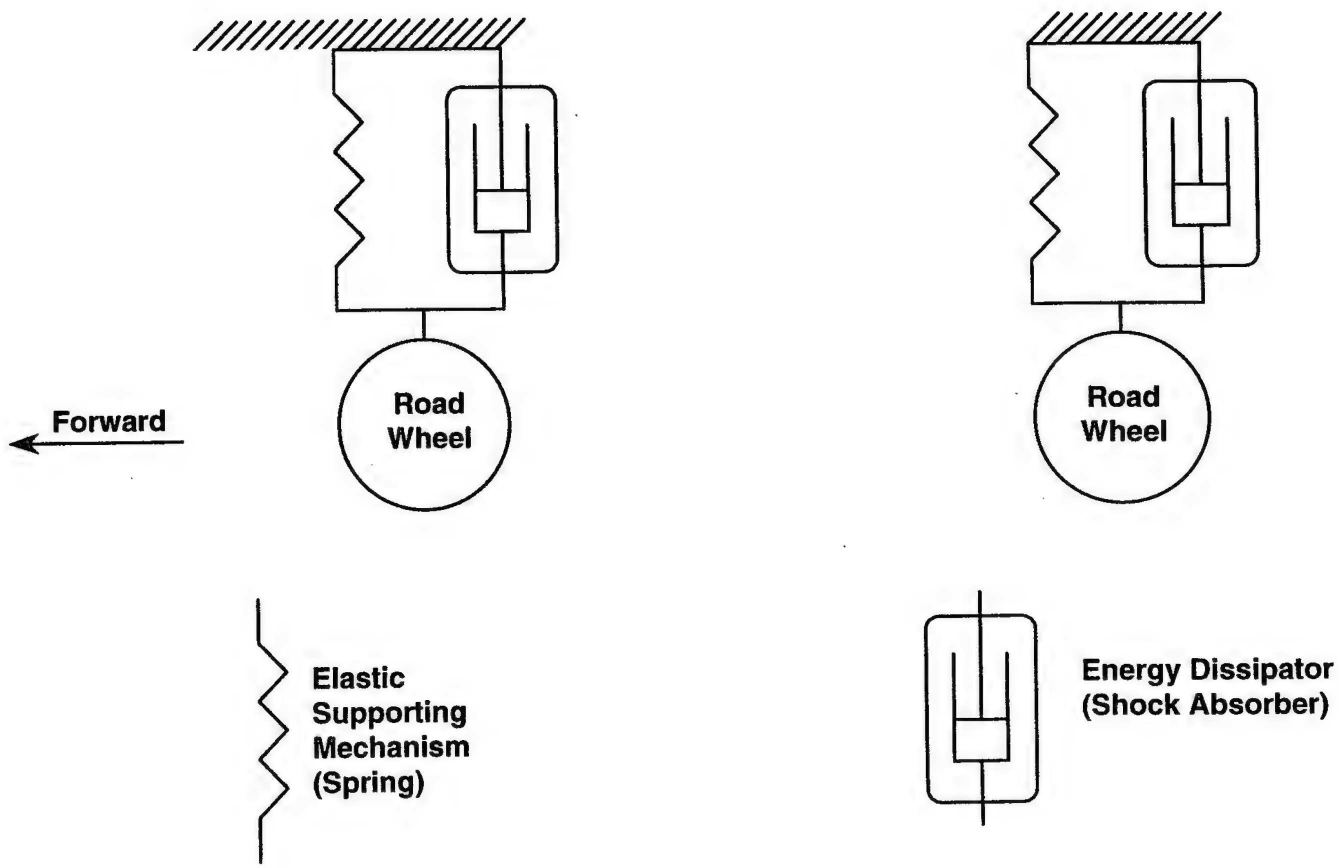
As a schematic, this only represents the functions of the mechanical elements. In practice, the spring can be steel or other elastic metal formed in a variety of shapes such as a coil or torsion bar. The function of the spring can also be accomplished by using a piston to enclose a liquid and a pressurized gas in a cylinder. One company, Davis Technologies, makes suspension struts for mining vehicles by using a compressible liquid.

Each design has its strengths and weaknesses. A particularly noteworthy example arose in the case of a hydropneumatic suspension to replace the torsion bar and rotary damper originally used on the M1 tank. Because of the tank's weight the working pressures can be very high, e.g., 13,000 psi. Making such a suspension that could be reliable in the rigorous environment of TCV operations required substantial investments and the development of a good deal of specialized engineering expertise and proprietary products.

Nevertheless, the essential point is that although the actual configuration of suspension systems can vary widely, in a standard system the behavior of the components is not continuously adjusted in response to the vehicle's motion.

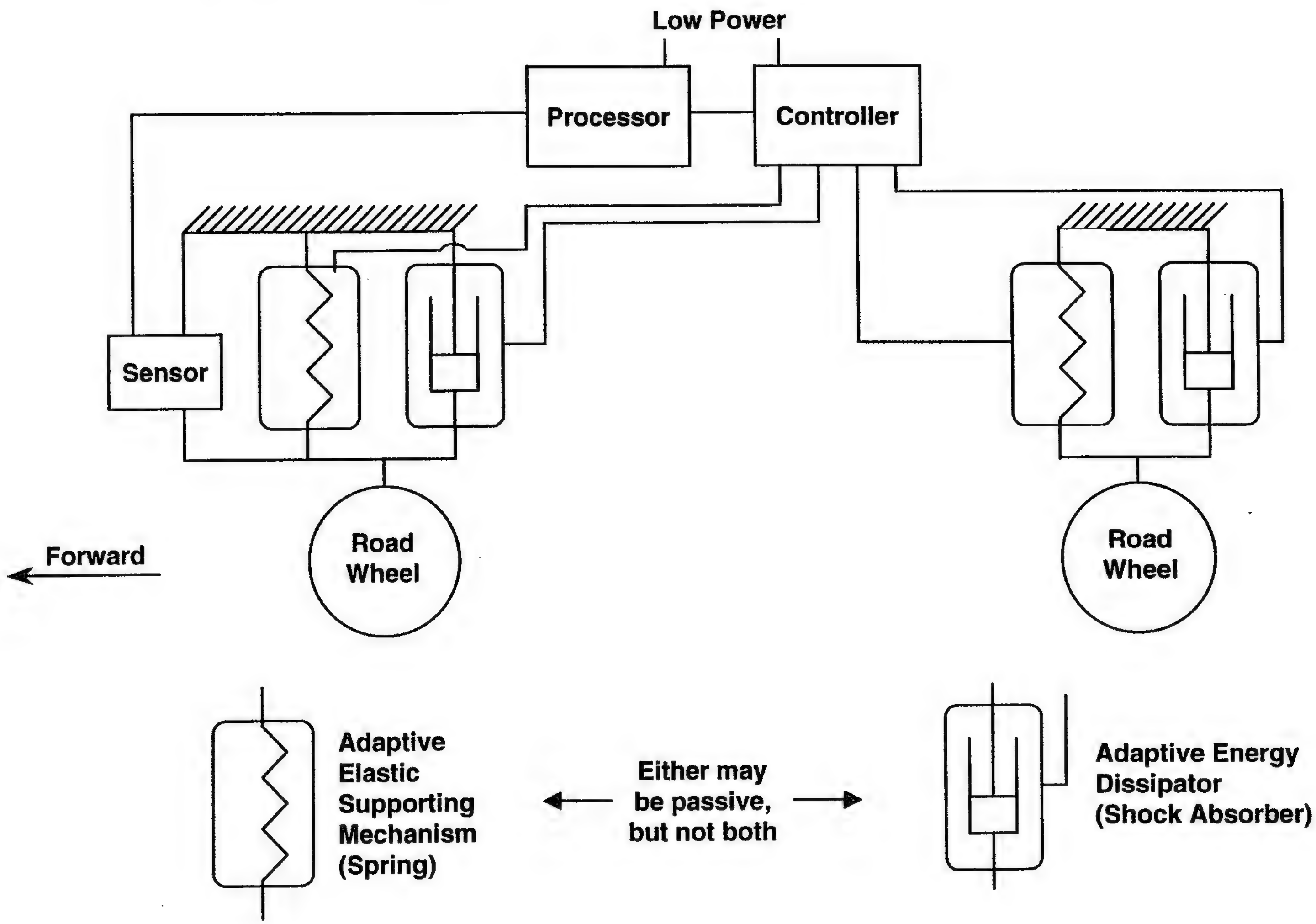
(A TCV typically also uses a drive sprocket to move the track, a number of idler wheels to support the track, and a tensioning idler to allow the track to flex without causing excessive tension or slack in it. Many of the design considerations applicable to the suspension are also applicable to the tensioning idlers.)

SCHEMATIC OF A STANDARD SUSPENSION



This figure illustrates the principal components of an adaptive suspension system. As in the case of the standard suspensions, the actual design of components and their configuration into a complete suspension system may be highly variable. The key feature is that there is an automated means of adjusting how the suspension system, and thus the vehicle, responds during maneuvers over potentially very rough terrain. Therefore, the adaptive system requires some power input, but it is only the power to operate the processor that receives the sensor outputs and the controller that adjusts the elastic support stiffness and the energy dissipator. It need not even be electric power, e.g., the control system could be based on fluidics. In any case, an algorithm for telling the controller how to adjust the components (and thereby adapt to the situation) must be developed and included as an element of the overall system.

SCHEMATIC OF AN ADAPTIVE SUSPENSION



The distinguishing feature of an active suspension system is the use of actuators in place of the elastic supports and the energy dissipators. These may be mechanical or electro-mechanical. For example, one design developed by the Southwest Research Institute uses hydraulic components pressurized by pumps that are mechanically connected to the engine. An alternative design by the Center for Electromechanics at the University of Texas in Austin uses a rack and pinion mechanism in which the pinion is driven by an electric motor.

The expected benefits are due to the ability of the suspension to lift the road wheels away from bumps and push them into depressions. An attendant cost is the need for a high power source. This power requirement is noteworthy because it may represent a significant fraction of the power output from the vehicle's engine.[1] Thus, a vehicle with an active suspension will either have less power for other needs or it will need a bigger engine.

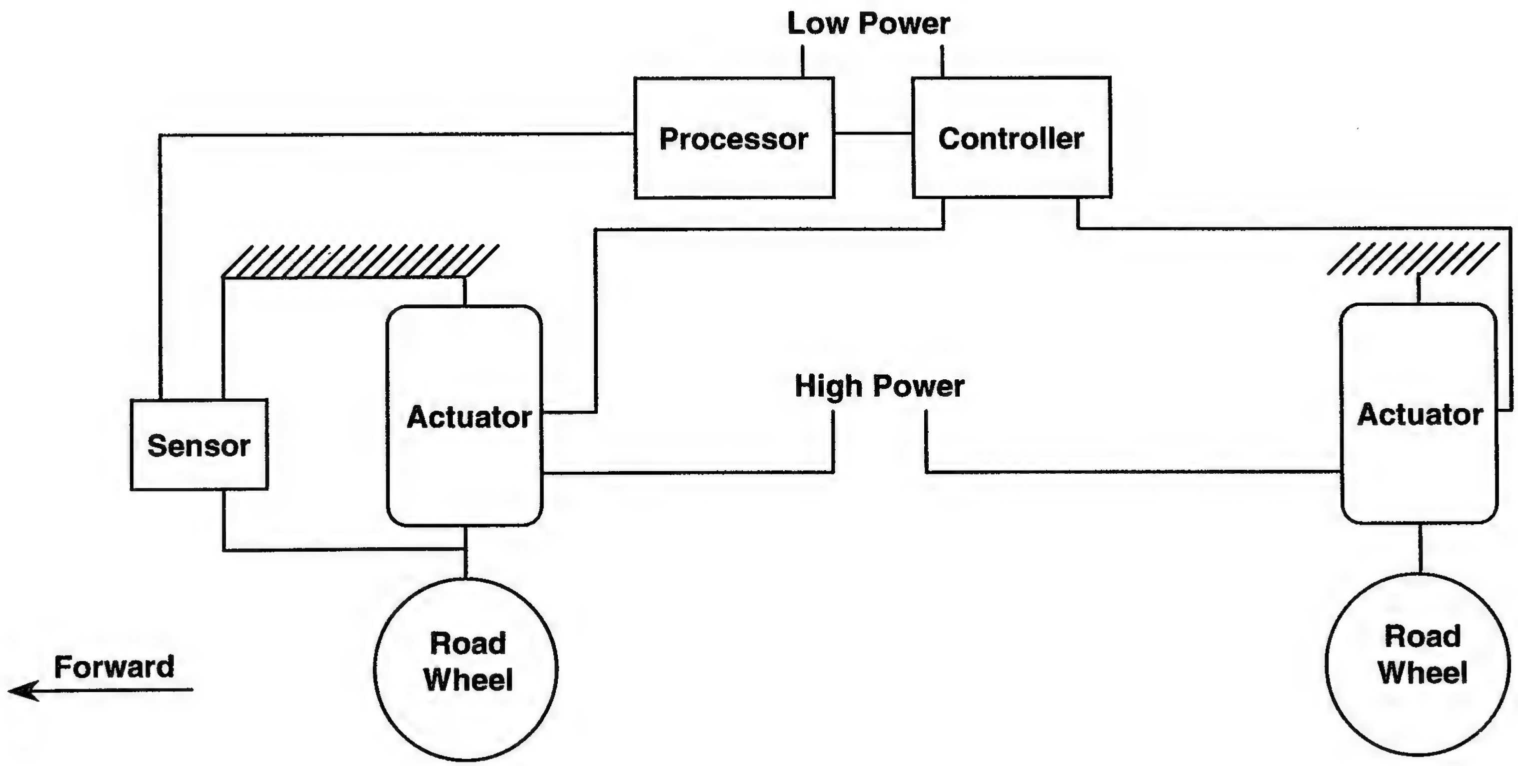
Although not mentioned earlier, there are at least two distinct types of active suspension systems. They differ by the source of the data used to control the suspension.

The system illustrated on the facing page is most similar to the adaptive systems in that the sensor package is used to measure the relative motion of one (or more) of the road wheels and the hull. (As in the adaptive system, it may also sense and report rotations, e.g., pitching, relative to the vehicle's center of gravity.) It is called a responding system because it responds to something that has already influenced the vehicle. For example, after the first road wheel hits a bump, the controller tells its suspension system, and possibly the systems on the other wheels, how to respond. As with the other types of suspensions, there are many active suspensions that differ by the details of their components.

---

1 In correspondence accompanying a technical report sent to the study team, Southwest Research Institute engineers predicted that an active suspension system would require approximately 40 hp to function properly in a hard maneuvering, 30,000-lb. bus.

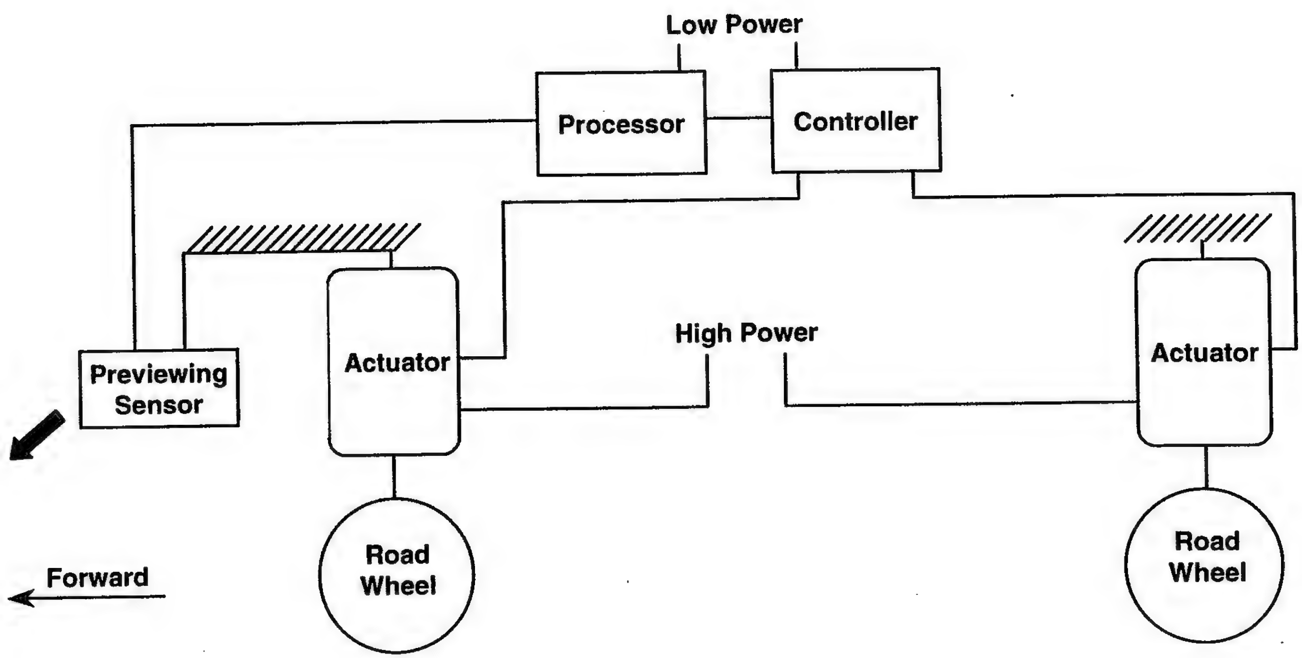
SCHEMATIC OF A RESPONDING ACTIVE SUSPENSION



Responding and previewing active suspensions differ by the source of the inputs to the processor. A responding system gets inputs from the relative motion of the wheel(s) and hull.

The second type of active suspension is the previewing system. In this type the response of the suspension is determined by inputs from a sensor package that looks ahead of the vehicle, i.e., it previews the terrain the vehicle is approaching and therefore the terrain that the suspension system must respond to. This clearly holds some potential benefits, e.g., it can reduce the shock of an initial encounter with an obstacle. On the other hand, it also embodies a number of difficulties. Foremost, perhaps, is the choice of sensor. Can it see through foliage? Can it recognize a puddle or tell whether a puddle is shallow or deep? Can it only look ahead or can it look in the direction toward which the vehicle is turning? These kinds of questions suggest why most discussions of previewing active suspensions deal with routine automotive applications rather than off-road applications.

SCHEMATIC OF A PREVIEWING ACTIVE SUSPENSION



Responding and previewing active suspensions differ by the source of the inputs to the processor. A previewing system uses a sensor that looks ahead of the vehicle.

This matrix summarizes the common configurations of standard, adaptive, and active suspensions as they have been defined above. Specifically, blank cells in each column identify the suspension system components to the left that are applicable to the suspension identified at the top. Shaded cells are "blacked out," i.e., they are not applicable to the suspension type at the top of the column.

The matrix also illustrates the conceptual framework for a complete data base of suppliers of both complete suspension systems and their components. In this application, manufacturers would be listed in each applicable cell. For example, all manufacturers of complete standard suspensions using hydro-pneumatic springs (elastic supports), namely General Dynamics Land Systems and Cadillac Gage Textron, would be listed in the first blank cell of the second column. Suppliers of the components they use would be listed in the appropriate lower cells in the same column. In this way, all suppliers of any particular type of component or suspension system would be immediately visible. Conversely, the matrix would also show the breadth of capability of any particular supplier of components.

Note the blank cells to the right of "Controller/ Algorithms." The development of adaptive and active suspension systems requires engineers with expertise in control theory to develop the control laws and then convert them to specific algorithms and tune them to the particular vehicle and suspension system. An example may help clarify the difference between developing the applicable control laws and tuning a specific algorithm.

Active suspension systems have been developed for and used on Formula 1 race cars. The control laws for them were developed to maintain a constant distance between the hull and the road so as to add aerodynamic down-forces for good traction. High forces on the driver are tolerable because of the short duration of the race relative to a soldier's indefinitely long sequence of duty days. After the control laws are implemented as algorithms, i.e., converted to a program for on-board controllers, the algorithms are tuned to account for specific conditions on the track or modifications to the car.

TCVs need different control laws, but the development concept is similar. With TCVs, height from the ground is less important than limiting the power transmitted to the crew due to vehicle motion. Again, even after the control laws are developed and converted to a useful algorithm, particular values of parameters may be adjusted to tune the response of the production vehicle to the production suspension.

COMMON SUSPENSION SYSTEM CONFIGURATIONS

			SUSPENSION TYPE					
			Standard (Passive)		Adaptive (Semi-Active)		Active	
			Standard	Hydro-pneumatic "Spring"	Adaptive[1] Damping	Adaptive[1] "Spring"	Responding	Previewing
SUSPENSION SYSTEM INTEGRATOR								
Components	Elastic Support (Spring)	Fixed K[2] Metallic		NA		NA	NA	NA
		Fixed K Hydro-pneumatic	NA	[3]		NA	NA	NA
		Adaptive K Hydro-pneumatic	NA	NA	NA		NA	NA
	Energy Dissipation (Shock Absorber)	Fixed Rate		[3]	NA		NA	NA
		Adaptive	NA	NA		NA	NA	NA
		Electro-Mechanical Actuator	NA	NA	NA	NA		
	Sensors	Wheel/Hull	NA	NA				NA
		Forward-Looking	NA	NA	NA	NA	NA	
		Controller/ Algorithms	NA	NA				
	Power Supply	Low Power	NA	NA				
		High Power	NA	NA	NA	NA		

1 A semi-active suspension can embody both adjustable, e.g., to lock the suspension.
2 K = Spring Constant
3 Components of the system may be manually adjustable, e.g., to lock the suspension.

The basic components of a suspension system for TCVs are the road wheels, road wheel arms that attach the wheels to the hull, springs of some sort, and shock absorbers. Suspension systems for the U.S. TCVs produced in the recent past use torsion bars as the springs and either rotary or linear shock absorbers. For the purposes of this study the important features are that neither the spring constant (i.e., a measure of how stiff the spring is) nor the rate at which the shock absorber can dissipate energy are automatically adjusted in response to the loads imposed on the suspension due to the TCV's movement. Both the spring and shock absorber are passive.

The U.S. Army Tank and Automotive Command, TACOM, is completing a study of the supplier base for TCV components including those mentioned above. (See Appendix C for more detailed information than is contained in this summary).

Briefly, the ability to obtain road wheels is stable due to many potential suppliers. Linear shock absorbers are essentially commercial products and there are many suppliers. There is only one supplier for rotary shock absorbers but this manufacturing area is also considered stable because there is a very limited demand driven only by new production for Abrams tanks. Torsion bars require complex manufacturing processes and are currently produced by three companies. Two, General Dynamics Land Systems (GDLS) and United Defense Limited Partnership (UDLP) produce torsion bars for the TCVs that they manufacture. Spencer Forge and Manufacturing is the only independent supplier for spares, and there is some concern that they may not stay in the business without reasonable assurance of a continuing demand. Although the skills and materials needed to manufacture traditional road wheel arms are considered widely available, the declining number of suppliers and the small quantities required lead TACOM to conclude that closer monitoring is necessary.

The following discussion of advanced suspensions addresses these concerns, albeit indirectly. They are addressed indirectly because our research has shown that recent work on suspension systems for TCVs does away with road wheel arms, torsion bars, and shock absorbers as independent components. Instead, all of the functions are being combined in a single integrated unit in which the spring action is accomplished hydropneumatically. This is the type of suspension being used on two major TCV development programs, Crusader and the Advanced Amphibious Armored Vehicle (AAAV). Furthermore, it is this unified design that appears to be the basis for the advanced, semi-active suspension systems discussed later.

THE INDUSTRIAL BASE FOR "TRADITIONAL" TCV SUSPENSION COMPONENTS[1]

- **ROAD WHEELS: TWO CURRENT U.S. SUPPLIERS AND SEVERAL INACTIVE SUPPLIERS, NOT A CONCERN**
- **SHOCK ABSORBERS: STABLE CAPACITY**
  - Linear shock absorbers are commercial items and there are many suppliers
  - Rotary shock absorbers are used on the Abrams tank. There is only one U.S. supplier but only small quantities are needed.
- **TORSION BARS (SPRINGS): THREE SUPPLIERS, DUE TO A COMPLEX MANUFACTURING PROCESS AND LOW PRODUCTION REQUIREMENTS; TACOM PROPOSES TO MONITOR THE VIABILITY OF THIS PRODUCTION CAPABILITY**
- **ROAD WHEEL ARMS: ONE GENERAL SUPPLIER AND ONE LIMITED TO ABRAMS TANK UPGRADES, AN AREA THAT TACOM DEEMS WORTHY OF MONITORING**

Separate road wheel arms, torsion bars, and shock absorbers are being superseded by integrated designs.

[1] Results of a study done by the Production Base Management Team, USA TACOM, "Tracked and Wheeled Vehicles Secondary Item Study," expected publication date of Feb/Mar, 1999, For Official Use Only

This matrix summarizes current TCV programs and related future programs in terms of the type of suspension they use and the phase of development they are in. One notable feature is movement away from torsion bars or other steel springs and separate energy dissipaters. Both of the systems in development use integrated hydro-pneumatic suspensions. This clearly suggests a future shift in the required industrial capacity for TCV suspensions away from torsion bar manufacturing and toward high-pressure hydro-pneumatic components.

A second, and perhaps more significant observation with respect to this study, is that adaptive or active suspension systems are not a part of any current acquisition program. Discussions with the Advanced Amphibious Armored Vehicle (AAAV) and the Crusader program offices reveal that adaptive suspension systems have been investigated, but testing has not shown that they are needed to meet the documented operational requirements. In fact, the suspension for the AAAV is designed so that it can be modified to be an adaptive system, but testing so far has not demonstrated a need to make the modification.

It is also noteworthy that the *House Appropriations FY 99 Defense Spending Report*[2] said, "The advent of a next generation replacement tank [is] at least 15 years away." The implication for this study is that it is impossible to foresee with any precision what specific industrial capabilities will be required when a new TCV acquisition begins. At this point it is at least as likely that the design of the new vehicle will be driven by the technology and production capabilities that are available at the time.

2 As reported in *Inside the Pentagon*, 25 June 1998, p. 8.

CURRENT TRACKED COMBAT VEHICLE PROGRAMS AND RELATED FUTURE PROGRAMS[1]

• CONTRACTORS RESPONSIBLE FOR THE SUSPENSION SYSTEMS ARE SHOWN BELOW EACH MDAP

Type of Suspension System		S&T/Pre-MDAP	Concept Exploration & Definition (0)	Program Definition & Risk Reduction (I)	Engineering & Manufacturing Development (II)	Production, Fielding/Deployment & Operational Support (III)
Standard (Passive)	Standard				Bradley FIST UDLP Grizzly UDLP Wolverine General Dynamics	Abrams (M1, M1A1, M1A2) General Dynamics Bradley (M2) UDLP C2V UDLP Hercules UDLP M270 MLRS Launcher UDLP
	Hydro-pneumatic "Spring"			AAAV Cadillac-Gage Crusader General Dynamics		Bradley M2/M3 (IFV/CFV)
Adaptive (Semi-Active)	Adaptive Damping	Future Scout & Cavalry System (GV.01.06)[2]				
	Adaptive "Spring"					
Active	Responding Active	Future Combat (GV.02.06)[2] Advanced Ground Vehicle Systems (GV.04.00)[2]				
	Previewing Active					
	Unknown at this time	Future Infantry Vehicle HMMLTV				

[1] Programs are identified more completely in Appendix A.
[2] 1998 Ground & Sea Vehicles Defense Technology Objectives (DTOs).

This chart summarizes the currently known requirements for suspensions for TCV and relates contractors to current TCV development programs. Note that there are only three contractors (though multiple divisions of a contractor may be involved).

REQUIREMENTS SUMMARY

- NO COMBAT VEHICLE MAJOR DEFENSE ACQUISITION PROGRAMS (MDAPS) REQUIRE ACTIVE OR ADAPTIVE SUSPENSIONS
- SYSTEMS IN DEVELOPMENT ARE DESIGNED WITH HYDRO-PNEUMATIC PASSIVE SUSPENSIONS

PROGRAM	AAAV (Phase I)	Crusader (Phase I)
PRIME CONTRACTOR	General Dynamics Land Systems (Muskegon, MI)	United Defense LP (Minneapolis, MN)
SUSPENSION SUPPLIER	Cadillac Gage Textron (New Orleans, LA)	General Dynamics Land Systems (Muskegon, MI)

- ACTIVE AND ADAPTIVE SYSTEMS BEING CONSIDERED FOR S&T AND PRE-MDAPS
  - Future Scout & Cavalry System (GV.01.06)[1] , Future Combat Vehicles (GV.02.06), Advanced Ground Vehicle Systems (GV.04.00)

[1]1998 Ground & Sea Vehicle DTOs.

As mentioned earlier, general literature searches revealed many organizations that are involved with advanced suspension systems in one way or another. Discussions at the Tank and Automotive Research and Development Center (TARDEC) were immensely helpful in identifying key participants in their R&D program. These contacts led in turn to others. The result of this investigation is the list in the left-most column of the facing matrix. It identifies manufacturers and R&D centers that have programs of potentially immediate relevance to TCVs. The check marks show the types of suspensions in which each organization is known to have relevant expertise.

It is noteworthy that although United Defense Limited Partnership has been a suspension system developer and has a current manufacturing capability, they apparently do not have an active R&D program. Their position is that TARDEC has its R&D program well in hand and that manufacturing even advanced suspension systems does not present any special technological challenges. Their primary interest is in production and the company can bid for production contracts on the basis of designs developed elsewhere. This is not to undervalue the engineering expertise that would be needed and is resident in UDLP to move a design into production. It is simply a statement of where that company has chosen to focus its energy.

The net effect is that there are only two U.S. manufacturers with a complete design, development, and manufacturing capability for complete suspension systems (as distinct from components). Rumors of due diligence examination of Textron Marine and Land Systems (including Cadillac Gage Textron) by General Dynamics Corp. were reported around June 1997 timeframe in InfoBase Defense Mergers & Acquisitions Database, December 1998. If GDLS should make a successful bid in the future for Cadillac Gage Textron, it would then be the only producer with full design and manufacturing capabilities for suspension systems for TCVs.

DEVELOPER SUMMARY

	SUSPENSION TYPE					
	Standard (Passive)		Adaptive (Semi-Active)		Active[1]	
	Standard	Hydro-pneumatic "Spring"	Adaptive Damping	Adaptive "Spring"	Responding	Previewing
GDLS Muskegon, MI	√	√	√	√	√	
Cadillac Gage Textron New Orleans, LA	√	√	√	√	√	
Davis Technologies, International Dallas, TX		√				
U of Texas Austin, TX					√	
U of California Berkeley, CA						√
U of Nevada Reno, NV			√			
Southwest Research Institute San Antonio, TX					√	

1 Web search revealed many links to sites citing automotive applications out of a total, for example, of over a million hits on the "Excite" search service.

Note: UDLP is not currently pursuing R&D of suspension systems.

In an effort to ascertain the strength of the manufacturing base, the study team drafted and sent a follow-up questionnaire to the three key manufacturers, General Dynamic Land Systems, UDLP, and the Cadillac Gage component of Textron. In brief it requested year by year summaries of the numbers and total sales value of the complete suspension systems produced since 1994. None of the companies completed and returned the questionnaire but General Dynamics did respond with a phone call to discuss the issues. The results of that conversation are summarized below.

GDLS' current and most significant suspension production for the U.S. is for the torsion bar and rotary damper for the Abrams series of tanks. However, because GDLS is also the prime contractor, the sales value (and even the production costs) of the suspension system components cannot be reliably extracted from the total costs. Furthermore, most of the over 100,000 Abrams suspension "stations" were produced prior to 1994. More recent production has been limited to approximately 120 vehicle sets (1680 stations) per year for 1994 through 1998 and a somewhat larger number of replacement units.

GDLS has also made three production runs of hydeopneumatic suspensions. In 1979 GDLS bought the National Water Lift (NWL) suspension product line which had produced linear hydropneumatic suspensions for the U.S. Army's Amphibious Mobile Bridge Launcher. When replacements were needed, GDLS produced 78 of them in 1985. Between 1980 and 1985 GDLS produced 3864 suspension units for Jordan. In the mid-1980s, GDLS also produced 2520 hydropneumatic suspensions for the Korean Indigenous Tank. (Korea produced more of these domestically.)

In short, because of the long time since GDLS (or the predecessor organizations that it has absorbed) has engaged in serial production of suspension systems, and because the other companies did not respond, the data that would have been most relevant to this study does not exist.

RECENT SUSPENSION SYSTEM PRODUCTION

- FOLLOW-UP LETTER SENT TO THREE KEY PRODUCERS OF U.S. SUSPENSION SYSTEMS
  - Requested numbers and dollar value (sales) for past 5 years

- NO WRITTEN RESPONSES BUT GDLS PROVIDED INFORMATION BY PHONE
  - Very little suspension system production over period of interest
  - Passive systems of both standard and hydropneumatic design have been produced in the 1980s

- CONCLUSION: DATA OF GREATEST INTEREST FOR THIS STUDY ARE NOT AVAILABLE BECAUSE IT DOES NOT EXIST OR WAS NOT PROVIDED BY THE MANUFACTURERS

As mentioned earlier, with respect to the basic engineering and manufacturing capabilities required, suspensions for TCV are quite similar to those for heavy-wheeled vehicles. Thus, although our research identified the U.S. contractors with significant current involvement in TCV programs, we also reviewed information about the product lines of U.S. manufacturers of heavy-duty vehicles for mining and construction.

Prominent examples of such manufacturers are shown on the facing chart. This demonstrates an ability to engineer and manufacture for both heavy loads and highway-like speeds, e.g., 35 to 40 mph. There is little doubt that they have the technical capability to produce (or acquire from their subcontractors and component suppliers) components for TCV suspension systems if they were given a design.

The Caterpillar Corporation is noteworthy in that it has a Defense and Federal Products Division, which the study team contacted. This is a small element of the company and in general has little influence on the R&D that Caterpillar does. On the other hand, it can draw from the R&D work to enhance construction equipment that they produce for the Department of Defense.

A particularly significant example of Caterpillar's potential is the Army's Deployable Universal Combat Earthmover (DEUCE). This is a tracked vehicle with a dozer blade. About 70 percent of its components are standard commercial items. It is capable of on and off road travel speeds of approximately 33 mph because of a rubber track and a hydropneumatic suspension that can be locked out to convert the DEUCE from its traveling configuration to its construction configuration as a bulldozer.

EXAMPLES OF OTHER POTENTIAL U.S. SOURCES OF SUSPENSIONS FOR TCVs

- All Season Vehicles, Inc.
  Grand Rapids, MN
- Case Construction Equipment
  Racine, WI
- Caterpillar, Inc.
  Peoria, IL
- CMI Corp.
  Oklahoma City, OK
- John Deere & Co.
  Moline, IL
- TEREX
  Westport, CT

Clearly, there are foreign producers of combat vehicles, both tracked and wheeled, as well as manufacturers of commercial products used for construction and mining. The listing on the facing page gives examples of companies in each category.

These foreign manufacturers of military equipment are known to produce either complete suspension systems or major components. (Appendix D contains more details about foreign manufacturers of combat vehicles and suspension capabilities they have demonstrated.) LOTUS in the U.K. is particularly interesting in that it has developed and installed active suspension systems in both a U.S. High-Mobility Multi-purpose Wheeled Vehicle (HMMWV) and a U.K. SCORPION (light tank) for demonstration and testing.

The study team did not contact the listed foreign manufacturers of commercial, heavy vehicles. Because they are competitors with the U.S. manufacturers shown previously, it is not unreasonable to attribute to them comparable engineering and manufacturing capabilities. Thus, they too could be potential bidders on contracts to produce suspension systems or components, or at least leads to their subcontractors and component suppliers.

FOREIGN SUPPLIERS

PRODUCERS FOR MILITARY APPLICATIONS[1]	PRODUCERS FOR CIVIL APPLICATIONS
Air-Log Ltd./EIS Group United Kingdom	Daewoo Heavy Industries Republic of Korea
Horstman Defense Systems Ltd. United Kingdom	Kawasaki Heavy Industries Japan
Krauss Maffei Wehrtechnik Gmph. Germany	Kobelco Construction Equipment Japan
Kuni BV Netherlands	Moxy Trucks Norway
Lotus Engineering United Kingdom	Samsung Construction Equipment Republic of Korea
Messier Auto Industrie France	Volvo Construction Equipment Sweden
Reumach Ermatek South Africa	
SAMM (Societe' d'Applications des Machine Matrice) France	
Vickers Defense Systems United Kingdom	

[1]See Appendix C for more details.

In order to identify R&D funding for advanced suspension systems, the study team both investigated contractual information in the relevant data bases and discussed the matter with TARDEC. However, a comprehensive listing of all sources of funds or even a simple total of all funding is not available. The reason is that funding for advanced suspensions is often contained in the funding for the larger systems of which they are a part, or in other larger R&D accounts.

Nevertheless, the discussions revealed three current or proposed contracts that offer a glimpse of what DoD is investing.

The largest is a $1 million contract awarded by DARPA and the National Automotive Center[1] to the Center for Electromechanics to develop and install an electromechanical, active suspension in a HMMWV.

A $750,000 contract, also related to active suspension systems for a HMMWV, was made to a small business as a follow-on to earlier work done under the Small Business Innovative Research (SBIR) Program that TARDEC uses. This work is focused on previewing sensors.

Finally, TARDEC expects to make at least one SBIR award of $75,000 in FY99 for an as yet unspecified project on advanced suspensions.

---

1 The National Automotive Center is the Army's center for the development of dual-needs/dual-use automotive technologies and their application to military ground vehicles.

FUNDING

- ONLY SOME OF THE GOVERNMENT FUNDING FOR SUSPENSION SYSTEM R&D IS READILY IDENTIFIABLE

Amount	Purpose
$1,000,000	Develop and install an active electromechanical suspension in a HMMWV
$750,000	Previewing sensors for possible use with an active suspension on a HMMWV
$75,000	Expected award this year under the Small Business Innovative Research Program (SBIR)

- ADDITIONAL FUNDING LIES WITHIN LARGER PROGRAMS USING 6.2 AND 6.3 MONEY

(This page is intentionally blank.)

FINDINGS AND CONCLUSIONS

In summary, we have found that there are no current requirements to produce adaptive or active suspension systems for tracked combat vehicles. Only two TCVs are currently in development as Major Defense Acquisition Programs (MDAPs), and testing done to date has shown that the vehicles can satisfy their requirements without adaptive or active suspensions.

Nevertheless, there are R&D programs addressing advanced suspension systems. Numerous, relevant projects have been found at the current developers of suspensions for TCVs, contract R&D centers such as the Southwest Research Institute, universities, etc.

This research did not discover the total current, U.S. government sponsored funding for advanced suspensions. It is known that at least $1,825,000 is allocated for the near term. Additional funding lies within larger programs that are being pursued with 6.2 and 6.3 money.

FINDINGS

- THERE ARE NO CURRENT PRODUCTION REQUIREMENTS FOR ADAPTIVE OR ACTIVE SUSPENSIONS ON TCVs
- R&D ON ADVANCED SUSPENSIONS IS WIDESPREAD
- ONLY $1,825,000 OF THE GOVERNMENT FUNDING FOR SUSPENSION SYSTEM R&D IS READILY IDENTIFIABLE
  - Other funding lies within larger programs using 6.2 and 6.3 money

Currently, there are only two prime contractors producing TCVs and both are capable of manufacturing suspensions for such vehicles. They are General Dynamics Land System (GDLS) and United Defense Limited Partnership (UDLP). This study has not discovered any evidence suggesting that they will lose the manufacturing capability needed to be viable producers of suspension systems in the future.

Also, two U.S. companies are currently engaged in the design as well as the manufacture of suspension systems for TCVs. These are GDLS and Cadillac Gage Textron.

Our research identified several foreign manufacturers of suspension systems or related components for TCVs. Moreover, there are many U.S. and foreign manufacturers of heavy construction and mining vehicles that carry loads and operate in environments similar to those of TCVs.

Discussions with engineers (principally at TARDEC and TACOM) suggest that, with the exception of hydropneumatic suspensions with very high working pressures and torsion bars for standard suspensions in the heaviest TCVs, the manufacturing capability needed to produce suspension systems is readily available. Moreover, there is no reason to believe that integrating even adaptive or active suspension systems into TCVs is beyond the capabilities of engineering departments at most heavy vehicle manufactures.

Clearly, further consolidation among the three contractors currently producing TCV suspensions should prompt a revisit of this subtier assessment. In fact, TACOM proposes to monitor more closely the production capacity for torsion bars and road wheel arms. However, separate torsion bars and road arms are being replaced in modern, passive suspensions with integrated, hydropneumatic designs. Currently and in short, however, there is no current production requirement for adaptive or active suspensions for TCVs. However, R&D programs and suspension manufacturing capabilities appear to be plentiful. Therefore, the industrial capability associated with this subtier assessment does not appear to warrant urgent concern.

FINDINGS (Cont'd)

- THE PRIME CONTRACTORS FOR TCVs–GDLS AND UDLP–ARE CAPABLE OF MANUFACTURING THE REQUIRED SUSPENSIONS
- TWO COMPANIES-GDLS AND CADILLAC GAGE TEXTRON-ARE DOING R&D AS WELL AS MANUFACTURING SUSPENSIONS
- THERE ARE SEVERAL FOREIGN MANUFACTURERS OF SUSPENSIONS AND RELATED COMPONENTS FOR COMBAT VEHICLES
- THERE ARE MANY U.S. AND FOREIGN MANUFACTURERS OF SUSPENSIONS FOR HEAVY CONSTRUCTION AND MINING VEHICLES
- PRODUCTION OF SUSPENSION SYSTEMS, EVEN FOR VERY HEAVY VEHICLES, DOES NOT APPARENTLY REQUIRE UNIQUE OR HARD-TO-FIND MANUFACTURING CAPABILITIES
  - Torsion bars for the heaviest TCVs are a possible exception but the production requirements are low and TACOM proposes to monitor the production base more closely

(This page is intentionally blank.)

Appendix A

TRACKED COMBAT VEHICLE PROGRAMS

Appendix A

TRACKED COMBAT VEHICLE PROGRAMS

ARMY (SOURCE: *WEAPON SYSTEMS, UNITED STATES ARMY 1998*)

Program / ACAT[1]	Status	Contractors (with >5% of total program value in FY 1997; primes in italics)	Points of Contact
Abrams (M1, M1A1, M1A2) / IC	Operations & Support (O&S) (IV), production is complete, upgrades continue	Allison Transmission (Indianapolis, IN) *General Dynamics* (Lima, OH; Warren/Sterling Heights, MI) LITCO (Idaho Falls, ID) Texas Instruments (Dallas, TX)	Project Manager, Abrams Tank System ATTN: SFAE-ASM-AB Warren, MI 48397-5000
Bradley M2 Infantry/M3 Cavalry Fighting Vehicle (IFV/CFV) / IC	O&S (IV) but A1s being upgraded to A2 configuration and A3 in Production (III)	HAC (LaGrange, GA) Lockheed Martin (Pittsfield, MA) MLS (San Jose, CA) Texas Instruments (McKinney, TX) *UDLP* (Rosslyn, VA)	Program Manager, Bradley Fighting Vehicle System ATTN: SFAE-ASM-BV Warren, MI 48397-5000
M113 Family of Vehicles (FOV) / III	O&S (IV)	Allison Transmission Indianapolis, IN) Detroit Diesel (Detroit, MI) *Anniston Army Depot (ANAD)* (Anniston, AL) *UDLP* (Rosslyn, VA)	Product Manager, U.S. Army Tank and Automotive Command AMCPM-M113 Warren, MI 48397-5000

Program / ACAT[1]	Status	Contractors (with >5% of total program value in FY 1997; primes in italics)	Points of Contact
Paladin / II	O&S (IV), production to continue through 1998	*UDLP* (Chambersburg, PA) Honeywell (St. Petersburg, FL) Lettterkenny Army Depot (Chambersburg, PA) Sechan Electronics (Lititz, PA) Watervliet Arsenal (Watervliet, NY)	Product Manager, Palladin/FAASV ATTN: SFAE-FAS-PAL Picatinny Arsenal, NJ 07806-5000
Command & Control Vehicle (C2V) / II	Production & Deployment (III)	Airflow (Fredericktown, MD) Brunswick (DeLand, FL) Cummins Engine (Columbus, IN) Lockheed Martin (San Jose, CA) *UDLP* (San Jose, CA; York, PA)	Product Manager, Command and Control Vehicle ATTN: SFAE-ASM-BV Warren, MI 48397-5000
Hercules / III	Production & Deployment (III)	*UDLP* (York, PA)	Project Manager, Combat Mobility Systems ATTN: SFAE-ASM-CV-R Warren, MI 488397-5000
Bradley Fire Support Team (BFIST) Vehicle / III	EMD (II), expect LRIP in FY98	*UDLP* (Rosslyn, VA) Systems Electronics (St. Louis, MO)	Product Manager, Bradley Fighting Vehicle System ATTN: SFAE-ASM-BV Warren, MI 48397-5000
Wolverine (Heavy Assault Bridge) / II	EMD (II) LRIP began in 97	*General Dynamics* (Lima, OH; *Sterling Heights, MI*) MAN GHH (Dusseldorf, Germany)	Project Manager, Combat Mobility Systems ATTN: SFAE-ASM-CV-H Warren, MI 48397-5000

Program / ACAT[1]	Status	Contractors (with >5% of total program value in FY 1997; primes in italics)	Points of Contact
Crusader / ID	Program Definition & Risk Reduction (I)	EDS (Herndon, VA) *UDLP* (Minneapolis, MN) General Dynamics (Sterling Heights, MI) Lockheed Martin (Burlington, VT) PRC (McLean, VA)	Project Manager, Crusader ATTN: SFAE-FAS-CR Picatinny Arsenal, NJ 07806-5000
Grizzly (Breacher) / II	EMD (II)	*UDLP* (York, PA)	Project Manager, Combat Mobility Systems ATTN: ASM-CV-B Warren, MI 48397-5000
M270 Launcher for Multiple Launch Rocket System (MLRS) Upgrade / IC	Production & Deployment (III)	*Lockheed Martin Vought Systems (Dallas, TX; Camden, AR)* Allied Signal (Teterboro, NJ) Atlantic Research (Camden, AR) Day & Zimm (Texarkana, TX) United Defense Limited Partnership (York, PA)	Project Manager, MLRS ATTN: SFAE-MSL-ML Redstone Arsenal, AL 35896
Navy/Marine			
AAAV / ID	Program Definition & Risk Reduction (I)	*General Dynamics* Cadillac Gage Ground Mobility Systems Operation of Textron Marine & Land Systems (New Orleans, LA)	Program Manager, AAAV AAAV Technology Center, DRPMAAAV 991 Annapolis Way Woodbridge, VA 22191-1215

Other Programs of Possible Interest
Future Scout and Cavalry System (FSCS)
Future Infantry Vehicle (FIV)
High Mobility Multi-Purpose Light Tactical Vehicle (HMMLTV)

[1] 1997 MDAP List (www.acq.osd.mil/api/asm/mdaplist.html).

Appendix B

ORGANIZATIONS AND POINTS OF CONTACT

Appendix B
ORGANIZATIONS AND POINTS OF CONTACT

Mr. Bill Altergott (Engineer on Crusader program and responsible for the integration of the suspension system into the vehicle)
United Defense Limited Partnership (UDLP)
Minneapolis, MN
612-572-5998

Mr. Richard Bayard
Advanced Amphibious Assault Vehicle (AAAV) Program Office
AAAV Technology Center, DRPMAAAV
991 Annapolis Way
Woodbridge, VA 22191-1215
703-492-3344

Dr. Joseph Beno
Program Manager, Electric Vehicle Program
Center for Electromechanics (CEM), University of Texas at Austin
J. J. Pickle Research Campus
10100 Bernet Road, EME 133
Austin, TX 78758
512-232-1619 (Fax: 512-471-0781)
j.beno@mail.utexas.edu

Dr. Faramarz Gordninejad
Dept. Of Mechanical Engineering/312
University of Nevada, Reno
Reno, NV 89557
faramarz@unr.edu
702-784-6990 (the department number is 784-6931)

Mr. Dan Grabelle
(Also Mr. Ed Hirych and Mr. Scott Huyser)
General Dynamics Land Systems
Muskegan, MI
616-724-2051

Professor J. Karl Hedrick, Director
Active Suspension Laboratory
Mechanical Engineering
The **University of California, Berkeley**
6195 Etcheverry Hall #1740
Berkeley, CA 94720-1740
510-642-2482 (Fax: 510-643-5599)
khedrick@me.berkeley.edu

Mr. Todd Herald
United Defense Limited Partnership (UDLP)
York, PA
717-225-8108

Mr. Frank (Francis) Hoogterp
Senior Research Engineer
Tank and Automotive Research and Development Command (TARDEC)
Warren, MI 48397
810-574-6378

Mr. Glenn O'Rourke
Director, Advanced Mobility Systems Operation
Cadillac Gage - Combat Vehicles (Division of Textron Marine and Land Systems)
6600 Plaza Drive
New Orleans, LA 70127-2584
504-253-6101 (Fax: 504-253-6123)

Mr. Martin Robinson
Member, Production Base Management Team
Tank and Automotive Command
Warren, MI 48397
810-574-7291

Mr. Glen R. Wendel, Manager
Hydraulic Systems Development
Department of Vehicle Systems Research
Southwest Research Institute
622 Culebra Road
P. O. Drawer 28510
San Antonio, TX 78228-0510

Appendix C

SUPPLIERS FOR COMPONENTS OF "TRADITIONAL" TCV SUSPENSION SYSTEMS

Appendix C
SUPPLIERS FOR COMPONENTS OF "TRADITIONAL" TCV SUSPENSION SYSTEM

This appendix is a brief synopsis of suspension system component supplier data taken from the study *Tracked and Wheeled Vehicles Secondary Item*, done by the Production Base Management Team at the U.S. Army Tank and Automotive Command. The study is to be published in the first quarter of 1999.

ROAD WHEELS

Supplier	Comments
B & C Machine, Barberton, Ohio	Active supplier of road wheels for the M1. A machine shop operating at 60% of its capacity. Defense production is 25% of its current business.
North American Molded Products, Hartville, Ohio	Active supplier of road wheels for the Bradley Fighting Vehicle System, M1113A3, M60/M88, and the M992 vehicle systems. TACOM's forecast for FY98-01 production is approximately 50% of the breakeven values needed for the company to keep the division making road wheels in operation.
Titan Wheel (now Titan International, Inc.) Quincy, Illinois	Inactive supplier. A machine and stamping shop.
North American Blanking (not found in the current, on-line edition of the "Thomas Register of American Manufacturers")	Inactive supplier of stampings used in road wheel production.
Urdan Industries, Ltd., Netanya, Israel	Inactive foreign supplier.
Suspension & Parts Industries, Inc., Haifa, Israel	Inactive foreign supplier.

SHOCK ABSORBERS

Suppliers	Comments
General Dynamics Land Systems, Scranton, Pennsylvania	Active supplier of rotary shock absorbers for the Abrams tank.[1] Its current sales are all defense related.
Suspension & Parts Industries, Inc., Haifa, Israel	Inactive supplier of rotary shock absorbers for the Abrams tank.

[1] Shock absorbers for other TCVs are of a traditional piston and cylinder design that is commercially based.

TORSION BARS

Suppliers	Comments
General Dynamics Land Systems, Scranton, Pennsylvania	Active supplier for production of heavy TCVs, e.g., the Abrams tank.
United Defense Limited Partnership, Anniston, Alabama	Active supplier for its production of medium to light TCVs, e.g., the M113 family of vehicles. Considers its torsion bar division to be "marginal."
Spencer Forge Manufacturing Co., Spencer, Ohio	Active and only independent supplier, i.e., only supplier of torsion bars for TCVs that is not a TCV prime contractor. Its torsion bar division is 100% defense related and is operating one shift with a skeleton crew.

ROAD WHEEL ARMS

Suppliers	Producers
LOC Performance Products, Inc., Plymouth, Michigan	Active supplier to prime contractors for TCVs and for the production of spares. Success at maintaining its production capability is expected to depend on its commercial (automotive-related) business.
General Dynamics Land Systems, Scranton, Pennsylvania	Active supplier for only the Abrams tank upgrade.

(This page is intentionally blank.)

Appendix D

FOREIGN MANUFACTURERS OF COMBAT VEHICLE SUSPENSION SYSTEMS/COMPONENTS

Appendix D
FOREIGN MANUFACTURERS OF COMBAT VEHICLE SUSPENSION SYSTEMS/ COMPONENTS*

FRANCE				
Company	Suspension Type: Total System	Suspension Type: **Components**	**Application Examples**	**Remarks**
Messier Auto Industrie		– Double-action lever-operated hydraulic dampers	– AMX-13 Light Tank – AMX-30 MBT – AMX-10P Tracked Vehicle – ALVIS(UK) Scorpion & Stomer Vehicles	– This damper along with torsion bars and bump stops completes a suspension.
	– Prototype hydro-pneumatic		– Some Leclerc test beds	– Controls ride angle and height with added regulator
		– Rotary hydraulic shock absorber	– Prototype status	– Installed in the same holes left upon torsion bar removal
	– Air-hydraulic shock absorber		– Prototype status	– Each unit acts as a spring and damper with operator height control.
	– In-arm integrated hydropneumatic		– Prototype status	– Performs both spring and damping functions

* Source: *Jane's Armor and Artillery Upgrade 1997-98.*

Company	Suspension Type		Application Examples	Remarks
	Total System	Components		
Samm (Societe' d'Applications des Machines Motrices)	– Linear hydro-pneumatic for light armored vehicles – Twin-cylinder-hydropneumatic suspension for tanks – MacPhearson hydropneumatic suspension		– On a number of wheeled/tracked vehicles under 25 metric tons – For new MBTs in the 50 metric ton class – Undergoing trials	– Height and attitude control may be added – May also replace torsion bars on existing vehicles – Can receive signals for attitude correction and height control

GERMANY

Company	Suspension Type		Application Examples	Remarks
	Total System	Components		
Krauss-Maffei Wehrtechnik Gmph.		– Hydraulic bump stops – Torsion bars	– Leopard1/2 MBTs – M41/48 LT MBT	– Damping force matches impact velocity – Improved torsion bar replacements

NETHERLANDS

Company	Suspension Type: Total System	Suspension Type: Components	Application Examples	Remarks
KONI BV.		– Hydraulic shock absorbers	– M113/AIFV Series and several other vehicles, internationally	– Supplies home/export mkts for AFVs, e.g., Belgium, Egypt, Germany, Netherlands

UNITED KINGDOM

Company	Suspension Type: Total System	Suspension Type: Components	Application Examples	Remarks
Air-Log Limited, specialists in hydropneumatic systems, (taken over by EIS Group plc in 1996)	– Hydropneumatic suspension named hydrogas (gas spring with integral hydraulic dampers)		– Challenger 1/2 MBT – AS90 155-mm artillery	– Spring force proportional to deflection rate
	– Hydrostrut (telescopic arrangement of the (above) hydrogas unit		– Tested on • Swedish Centurian MBT • British Chieftain MBT, AVLB and recovery veh.	– Provides advantages of hydrpneumatics in a small volume
	– Tandem hydrostrut		– For AFV retrofit market	– Combined spring/damper added to existing torsion bars

Company	Suspension Type		Application Examples	Remarks
	Total System	Components		
Horstman Defence Systems Ltd. (Also owned by EIS Group plc)		– Integrated rotary dampers	– Warrior ACV (U.K.) – Swedish Cbt. Vehicle 9030	– Widely compatible with existing torsion bar installations
		– Lever actuated dampers	– UK FY432 APC, M113 – UK Scorpion CVR(T)	– Improved damping and easily retrofitte
		– Vehicle suspen. Lockouts	– In production, easily added	– In service in U.K., Kuwait, Norway
Lotus Engineering	– Active suspension (development)		– U.K. Scorpion CVR (tracked) – U.S. HMMWV M1026	– Development Pgm. HMMWV install. Funded thru GDLS.
Vickers Defence Systems		– Hydraulic track tensioner	– Chieftain AVLB & ARRV – Challenger 1/ 2 MBTs – U.S. M1 MBT for test (bought by GDLS)	– Development complete. Production as required. In service on Challenger 2 in Oman.

INTERNATIONAL TEAM

Company	Suspension Type		Application Examples	Remarks
	Total System	Components		
Horstman Defence Systems Ltd (UK) and Reumech Ermatek (S. Africa)		– Adaptive damping system	– None, as yet. Potentially, S. Africa LIW, and U.K. Mk 1B MBT	– Development, not yet in production or service. Uses body/swingarm motion sensors, and computer control.

(This page is intentionally blank.)

Appendix E

GLOSSARY

Appendix E
GLOSSARY

AAAV	Advanced Amphibious Armored Vehicle
ACV	Advanced Cavalry Vehicle
AFV	Advanced Fighting Vehicle
APC	Armored Personnel Carrier
AVLB	Armored Vehicle Launched Bridge
C2V	Command and Control Vehicle
CVR	Combat Vehicle Reconnaissance
DEUCE	Deployable Universal Combat Earthmover
DTAP	Defense Technology Area Plan (for Manufacturing Technology)
DTO	Defense Technology Objectives
EMD	Engineering and Manufacturing Development
FISTV	Fire Support Team Vehicle
GDLS	General Dynamics Land Systems
hp	Horsepower
HMMLTV	High-Mobility Multi-purpose Light Tactical Vehicle
HMMWV	High-Mobility Multi-purpose Wheeled Vehicle
IFC/CFV	Infantry Fighting Vehicle/Calvary Fighting Vehicle

Kph	Kilometers per hour
LIW	Littleton Engineering Works (South Africa)
LRIP	Low Rate Initial Production
MDAP	Major Defense Acquisition Program
MLRS	Multiple-Launcher Rocket System
O&S	Operations and Support
PDRR	Program Definition and Risk Reduction
psi	Pounds per square inch
R&D	Research and Development
S&T	Science and Technology
TARDEC	Tank and Automotive Research and Development Center
TCV	Tracked Combat Vehicle
UDLP	United Defense Limited Partnership

Appendix F

DISTRIBUTION LIST

Appendix F
DISTRIBUTION LIST

Office of the Secretary of Defense	No. of copies
Mr. Martin Meth Director, Industrial Capabilities and Assessments Office of the Deputy Under Secretary of Defense Industrial Affairs and Installations 1777 N. Kent Street Suite 11400 Rosslyn, VA 22209	2
Mr. Robert Read Office of the Director Industrial Capabilities & Assessments 5203 Leesburg Pike, Suite 1403 Skyline 2 Falls Church, VA 22041	10
Mr. Steven C. Grundman DUSD(IA&I) 3330 Defense Pentagon, Room 3E813 Washington, DC 20301-3330	1
Mr. Victor Ciardello ODUSD(IA&I)/FEA 3330 Defense Pentagon, Room 2A318 Washington, DC 20301-3330	1

Office of the Secretary of Defense	**No. of copies**
Dr. George Schneiter Director, S&TS 3090 Defense Pentagon, Room 3E130 Washington, DC 20301-3090	1
Honorable Hans Mark Director, DDR&E 3030 Defense Pentagon, Room 3E808 Washington, DC 20301-3030	1
Department of the Army	
Mr. Frank (Francis) Hoogterp Senior Research Engineer Tank and Automotive Research and Development Command (TARDEC) Warren, MI 48397	1
Mr. Martin Robinson Member, Production Base Management Team Tank and Automotive Command Warren, MI 48397	1
Mr. Paul Hoeper Department of the Army Assistant Secretary for RDA 103 Army Pentagon, Room 2E672 Washington, DC 20310-0103	1

Department of the Navy	**No. of copies**
Dr. Lee Buchanan Department of the Navy OASN-RDA 1000 Navy Pentagon, Room 4E741 Washington, DC 20350-1000	1
Defense Agencies	
Dr. Frank L. Fernandez, Director Defense Advanced Research Projects Agency (DARPA) 3701 N. Fairfax Drive, Room 983 Arlington, VA 22203-1714	1
Other Organizations	
Defense Technical Information Center 8725 John J. Kingman Road, STE 0944 Fort Belvoir, VA 22060-6218	2
Institute for Defense Analyses 1801 N. Beauregard Street Alexandria, VA 22211-1773	22
Total No.	**45**

(This page is intentionally blank.)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1998	Final

4. TITLE AND SUBTITLE

Subtier Assessment: Advanced Suspension Systems for Tracked Combat Vehicles

5. FUNDING NUMBERS

DASW01-94-C-0054

T-AV5-1561

6. AUTHOR(S)

Joseph E. Hartka

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER

IDA Paper P-3448

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Director, Industrial Capabilities and Assessments
Office of the Deputy Under Secretary of Defense
Industrial Affairs and Installations
1777 N. Kent Street, Suite 11400
Rosslyn, VA 22209

FFRDC Programs
2001 N. Beauregard Street
Alexandria, VA 22311-1772

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study addressed the industrial suppliers for suspension systems and their components for tracked combat vehicles (TCVs). It contains a summary of findings by another study group that addressed suspension systems for current TCVs. It provides original research on the components and related manufacturers for adaptive or active systems in which the rate of energy storage or dissipation by the suspension system is automatically adjusted to improve the system's performance. The study concludes that although some manufacturing capabilities should be monitored, the industrial capacity to produce suspension systems for TCVs does not warrant urgent concern by the Department of Defense.

14. SUBJECT TERMS

combat vehicles, tracked combat vehicles, suspension systems, active suspension, adaptive suspension, industrial base, manufacturing capabilities, TCV subtier suppliers

15. NUMBER OF PAGES

102

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Same as Report

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102